REACTIONS TO LIGHT AND MECHANICAL STIMULI IN THE EARTHWORM PERICHÆTA BERMUDENSIS (BEDDARD).

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Recent work concerning the behavior of earthworms has related chiefly to their reactions to light. Since the contributions of Hofmeister and Darwin, and that of Hesse ('96) there have been a group of recent papers by Parker and Arkin, Miss Smith, Adams and Holmes, which have been devoted chiefly to the directive influence of light. In the present state of the discussion of this subject the current theory of tropisms has been called in question, according to which the earthworm is oriented directly by light. Holmes has shown that light induces a general state of activity leading to random movements of which those toward the light are checked and those away from it continued, this resulting in final orientation.

This paper aims to show that random movements are a feature of less strong light, tending to disappear with the increase of intensity, and are replaced by direct orientation in very strong light. It is also shown experimentally that the earthworm is more sensitive in the extended than in the contracted state, and that this has an important bearing upon the production of random movements. The explanation given of this is that when extended the sensitive elements of the skin are expanded over a greater surface. This is shown to have a bearing upon the production of random movements as follows: Locomotion consists of a succession of extensions and contractions and as each extension begins in a state of lower sensibility the anterior end may be projected toward the light, only to be checked when its increase of sensibility with extension makes the stimulus appreciated. Movements away from the light are not so checked. In stronger light the sensibility of the worm when contracted is sufficient to suppress movements toward the light at the outset. In such light the worm appears to be orientated without trial movements. It is important that the worms be kept in the dark before all experi-

ments, as their discrimination diminishes and random movements begin again when this is the case.

It is shown that the reactions which are typical of the life in the burrow are more definite and controlled by weaker stimuli than reactions in the open, and this may be expressed by saying that the earthworm's organization is more highly adapted for life in the burrow. Reactions in the axial direction are definite and more sensitive to stimuli than lateral movements in response to light.

The genus *Perichæta* is noted for its agility, and of its special reactions the leaping movements are the most notable.

Description of the Species.

Perichæta, the eel-worm, as it is called by gardeners, is an exotic genus of earthworms which is said to be quite commonly established in greenhouses in the old world, and also in gardens in parts of France, where they have been introduced, it is said, from the east. The only mention of *Perichæta* having been found in this country, that has come under the writer's notice, is that of Garman, who reported a species of *Perichæta* as becoming established in greenhouses in Urbana, Ill. The writer found *Perichæta bermudensis* (Beddard) in a greenhouse in Evanston, Ill. In suitable conditions of soil these worms flourish in great abundance.

The genus *Perichæta* is noted for its activity. The squirming movements which have given it its name of eel-worm are a striking exhibition of agility. This sort of movement is not confined to *Perichæta*, but is developed in the genus to an extent not found elsewhere. By alternate contractions of the longitudinal muscle bands it makes a series of leaps, by which it may waltz about for quite a distance. It reacts in this way when handled or disturbed, as when uncovered from its burrow.

The worms are of rather large size. They are found often measuring nine inches in lengh when killed fully extended. They are rather pointed at both ends. The continuous circles of setæ on each segment give the name to the family. The clitellum is a complete band or girdle encircling segments 14–16. A large pair of spermiducal glands shine through the opalescent

skin behind the clitellum, making a conspicuous mark. The dorsal pores are very prominent, exuding an abundant yellowish mucus. The everted buccal cavity is used as a proboscis, and is thrust out constantly in its feeling movements. The blood vessels are prominent, shining distinctly through the skin. The very numerous, minute, diffuse nephridia are a feature which, along with the continuous circles of setæ, have caused considerable discussion as to whether these conditions are primitive for earthworms or secondarily derived.

The Theory of Tropisms.

The orientations to light and other stimuli, which are among the most striking phenomena in the behavior of the lower animals, have received various explanations. After the first anthropomorphic explanations of these movements, based upon likes and dislikes, there came an apparent revolution of ideas bringing in explanations of seemingly great simplicity. As the physiology of plants, particularly of the higher plants, had made considerable progress towards a solid physico-chemical basis, there was a transference of conceptions based upon plant physiology to the realm of animal behavior and the orientations of the lower animals were illuminated by analogies drawn from plants. For example, we find the assertion of identity between heliotropic phenomena in plants and animals. The mechanism of the tropism was not a reflex according to this conception, but was a unique form of movement to be added to the classification of animal movements into reflex, instinctive and voluntary.

The current theory of phototropic or -tactic phenomena as applied, for example, to the earthworm, was that when light strikes one side of the animal so as to cause unequal stimulation of the two sides, it changes the tone of the muscles on the side affected. The muscles of one side are thus either relaxed or their tension is increased according as the animal happens to be positively or negatively phototropic. It is bent away from or toward the source of stimulation by the direct action of the environment upon the protoplasm. The tropism is accordingly regarded as a peculiar kind of forced movement, dependent upon the chemical nature of the protoplasm.

Jennings has shown in the case of the Protozoa and also the Rotifera that the tropism theory gives an untrue explanation of the mechanism of orientation. These animals are not directly swerved away from or toward the source of stimulation, but they have their peculiar methods of reaction and orientation in the direction of the stimuli is effected by a sort of "trial and error" method.

Reactions of Earthworms to Light.

Since Darwin's account of the habits of earthworms there has been a series of papers devoted chiefly to the directive action of light upon these forms. Parker and Arkin, Miss Smith, Adams and Holmes have studied the reactions of earthworms crawling over surfaces, exposed to light stimulation from one side.

Parker and Arkin observed the head movements of worms placed at right angles to the direction of the light and determined that 65 per cent. of the movements were indifferent, *i. e.*, straight ahead, 30 per cent. were away from the light and 4 per cent. toward it. They regarded the various head movements in different directions as due to a variety of chiefly undefined causes in addition to light and since 4 per cent. were toward the light they assume that as many of the negative responses would be due to other causes than light. So subtracting 4 per cent. from 30 per cent. the remaining 26 per cent. they regard as the measure of the negative phototactic response. Adams showed in addition that the earthworm is positive to very weak light.

The observers mentioned did not consider the question of the mechanism of orientation. Holmes takes up the current tropism theory and questions its explanation of the mechanism of orientation for these animals. He shows that the various extension movements appear to be of a simply random character, due to a general stimulation by light. The way in which orientation is effected he describes as follows. Movements that are toward the light are checked and the animal draws back and usually moves in the opposite direction. Movements away from the light do not lead to further stimulation and so are prolonged farther, and as a final result of such random movements, the worm gets into the direction of the rays, in which position the stimulation of the sensitive anterior end is least, and it then continues to move

straight ahead. Any swerving from this path leads to an increase of stimulation and hence is corrected. Holmes regards none of the movements as forced by light. All are random in direction but certain favorable ones are followed up and unfavorable ones checked by the increase of stimulation resulting from them.

Holmes proposes his theory of the "selection of random movements" only as one factor in phototaxis, not wishing to exclude the possibility of a slight amount of directive influence in the light. His reason for so doing is based on the observation of himself and the other experimenters alluded to that there is an excess of negative turnings over positive ones. Of course if the movements of the animal are random there should be an equal number of movements in the positive direction as in the negative, when one considers only the first movements occurring after stimulation. Holmes counted a number of first movements and found them about as equally divided between the positive and negative side as could perhaps be expected (23 : 27). Parker and Arkin found an excess of negative movements over positive of 26 per cent. Miss Smith (on the same basis of reckoning) found an excess of 39 per cent. and Adams, using different intensities of light, found that the excess was greater with an increase in the intensity. If the observers did not count only the first movements after stimulation but also many subsequent movements, the excess of negative movements is not against the supposition of their random character. It may be well for clearness to suppose a case. Of one hundred first movements after stimulation (when the worms are placed at right angles to the light) there should be an equal number of positive and negative, if they are purely random. But according to the theory, negative movements tend to be continued while the positive ones are checked and may be followed by negative movements. This would give rise to an excess of negative movements in any large number that were counted. Holmes says that the excess of negative movements may be due to one of three causes—accident, failure to count many of the slight positive movements which are easily overlooked, or to a slight orienting tendency of the light. Holmes undoubtedly has in mind first movements only, when he assumes that an excess of negative movements is against the supposition of their random character.

Holmes's theory of the "selection of random movements as a factor in phototaxis" is thus based upon observational evidence which is easy to verify. It is easy to observe that the movements toward the light are apt to be checked and the movements away to be more prolonged. It is less easy to note in weak light, as the final result of orientation takes longer in that case.

Absence of Random Movements in Negative Phototaxis in Very Strong Light.

All of the experimenters referred to used artificial light except Miss Smith, who used diffuse daylight. Since all of them but Holmes took for granted the direct orienting power of light, they did not care to put the matter to a crucial test. It would seem that a test of the orienting power of light would require the use of lights of various strength, and especially of very strong intensity, since the perceptive power for light is so poorly developed in the earthworm. A test of the orienting power of direct sunlight is a very easy thing to make. Place the earthworm upon a sheet of wet paper in a beam of direct sunlight from a window. The light may be passed through a water chamber. The results are sufficiently obvious as to leave no doubt of their general nature. *Perichæta* is oriented directly away from the light, when placed at right angles to the rays. The first effect is a turning of the anterior end away from the light and by a series of turns the worm gets into the oriented position and crawls directly away. Usually the result is produced without a false movement. It is immaterial whether heat effects are excluded by passing the light through water or not. A species of *Lumbricus* was experimented with and behaved in the same manner.

If the sheet of paper is turned as the worm turns, so as to keep it at right angles to the rays the worm will travel in a circle continuously. To show the difference between the orienting effect of sunlight and that of an ordinary artificial light the following experiment was tried. By using a sort of searchlight consisting of a tube of asbestos paper surrounding a 32 c.p. incandescent light and narrowed to a small aperture, the light was so manipulated by the hands as to keep it constantly directed upon the anterior end of the worm, with the worm at right angles to the

rays. In this way the worm was kept under constant stimulation and caused to turn through one complete revolution and the time required was noted. The process of turning was slow and was effected by a series of readjustments involving many trial movements in the opposite direction. Most commonly about two minutes was necessary. In twenty such cases the average time required was five minutes, the greatest time, twenty minutes.

In the beam of sunlight as before stated the worm turns continuously without trial movements. The difference in behavior in the two cases is so striking that the occurrence of an occasional positive random movement in the sunlight is plainly seen not to affect the general result. When the worm is exposed to the sunlight, if a passing cloud obscures the sun, random movements begin to appear. Miss Smith, who used diffuse daylight from a north window, observed that the worm moves in a general direction away from the light, but in an uncertain manner. Adams, using a graded series of artificial lights, showed that the per cent. of negative movements increased with the intensity. Adams did not observe the whole process of orientation since he placed the worms in an illuminated box and observed the direction of their movement after an interval of stimulation. Holmes used artificial light of only one strength. A Welsbach burner was also used to give an intermediate intensity between those before mentioned. Worms were used that had been kept in the dark and they were brought suddenly into this powerful light. They all moved away from the light with very little appearance of random movements. At each forward extension they would turn a little away from the light so that their path appeared like a curve. It is not meant to be stated that there were no random movements. But there could be no hesitation in saying that there was a decided difference in their reaction under the stronger light. Fresh worms would by a series of turns get into the oriented position frequently without a noticeable random movement. If the worms were kept in the light for some minutes, they lost sensitiveness and their random movements began to be evident.

Occurrence of Positive Phototropism.

When using a 32-candle-power incandescent light it was noticed that some individuals behaved positively. About 6 per cent. of 200 worms tested showed the positive reaction. But at a few inches distance from the light these worms would apparently become negative. Heat effects were not excluded however. The following is a typical instance. An earthworm crawling on a table moved straight toward a 32-candle-power incandescent light until within a few inches, when it began to swerve and without pausing moved in a continuous curve away from the light until it was in the line of the rays, when it continued to move in a straight line away from the light.

Difference in the Sensibility of Earthworms to Light in the Contracted and Expanded State and the Bearing of this fact upon the Production of Random Movements.

The conclusion reached is that earthworms are oriented directly by light, but owing to their low degree of sensitiveness their movements are uncertain except in very strong light. The influence of light produces a number of noticeable effects upon the behavior. First, there is a state of general stimulation or restlessness inducing locomotion. Second, in light not strong enough to produce direct orientation the worm projects its anterior end in any direction. If toward the light, the worm after stretching out its anterior end will again retract it as if stimulated. If the worm is checked only after making an extension movement toward the light, the conclusion would seem to be that the anterior end is more sensitive when extended than when in the contracted condition. One may test this conclusion by further experiment. If a light is flashed suddenly upon a contracted worm the influence of the stimulus seems to affect it gradually, leading after an interval to movements. The extended anterior end responds far more quickly to sudden changes of stimulation. The basis for this difference in reaction must be in the fact that when the head is extended the sensitive elements in the skin are spread out over more surface than in the contracted state. A simple experiment will illustrate this fact. If an earthworm is

crawling on a moist paper it may be shaded by the hand or otherwise. When the worm crawls to the edge of the shadow and thrusts out its anterior end into the light it is jerked back suddenly. But if the light be thrown upon the worm when contracted, there is no sudden response, but only a gradual awakening to stimulation, as evidenced by subsequent movements. The bearing of this observation upon the movements of the worm would seem to be as follows: The worm contracted is like an animal with its eyes partly closed. It extends its head at random, thus gradually receiving the full stimulation upon its surface. If the movement is toward the light, this causes it to contract more or less and so check stimulation. If the movement is away from the light, the oblique illumination produces less stimulation and the movement is more prolonged. An animal with eyes, as a crustacean, or an insect, is of course so organized that movements toward the light may be checked, as it were, at the outset, in the case of negatively phototactic animals.

It is to be observed that the earthworm begins these random movements while in the contracted state. After extension it draws up its body by means of the longitudinal muscles and is therefore in the contracted state. It then advances again, and at each advance there may be a random change in direction. Thus the worm begins these random movements when in the contracted state and under minimum stimulation. The nature of its locomotion and of the sensitive elements in its skin necessitates the alternation of states of low and high sensitiveness. The random movements of an earthworm under light stimulation are consequently of an entirely special character, due to causes inherent in its structure.

To recapitulate, three situations in regard to light have been described, with their characteristic reactions. First, in weak light, second in strong light and third in a situation involving change of light intensity.

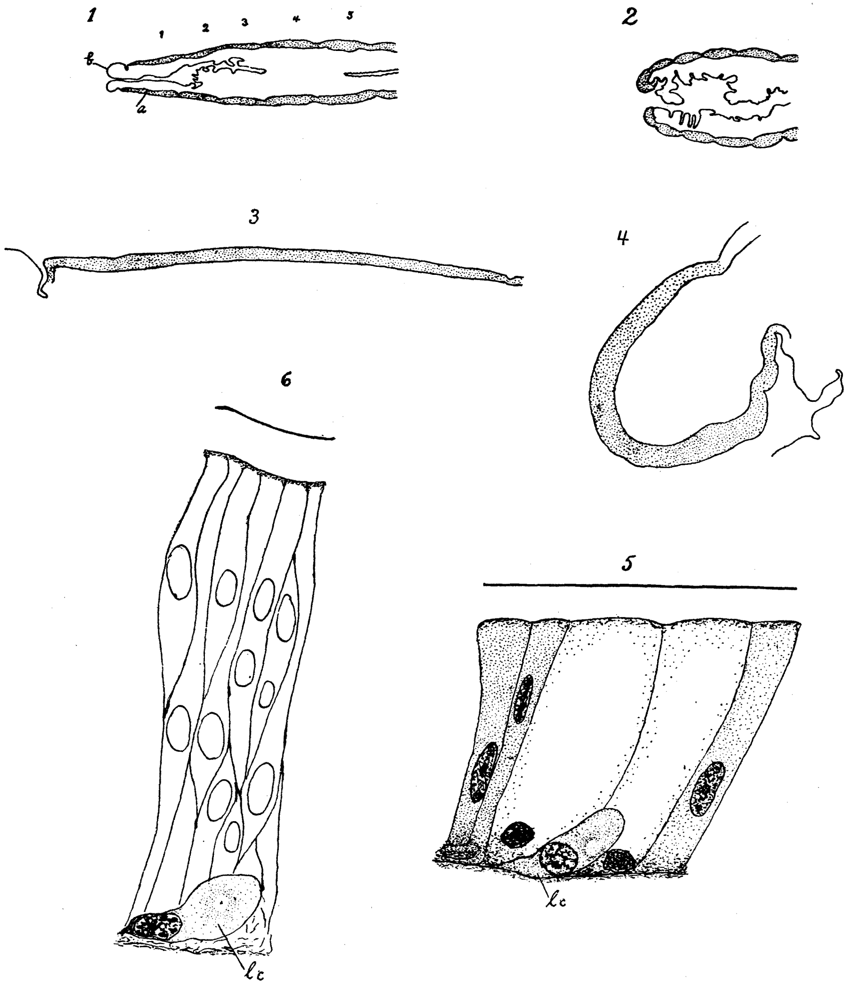
The stimulus of a change in intensity causes the animal to draw back its anterior end slightly and it then usually alters its course. When crawling under the influence of sufficiently strong light, it bends its head away from the light at each successive advance, until it gets into the oriented position. In light not

strong enough to have the directive effect its extension movements are random, an advance toward the light being checked and orientation being brought about by following up of favorable random movements. There are only two responses in reality, the checking or drawing back of the head involving the symmetrical use of the longitudinal muscles of both sides, and the turning response, involving the longitudinal muscles of only one side, that opposite to the source of stimulation. The two responses may also be combined.

The Anatomical Basis for the Difference in Sensitiveness to Light in the Extended and in the Contracted State.

The text figures introduced are intended to make clear the reason for the difference in the sensibility to light of the anterior end in the contracted and extended state. Hesse, who has worked on the organs of light perception of the lower animals, has shown the structure of the light cells in many species of earthworms and has worked out their distribution segmentally. He shows that these cells are most numerous on the first segment, and especially on the prostomium (which is fused with the first segment in *Perichæta*) and that their number diminishes rapidly on each segment as we go farther back. It is consequently the very tip of the animal (the posterior tip as well) which is most important for the perception of light, although light cells are found in small numbers over the whole length of the body.

The sections of *Perichæta* (Figs. 1 and 2) show that the first segments are subject to great extension and contraction. It was not possible to get the worm fixed in the fullest state of either extension or contraction. In Fig. 2 it is seen that the first segment is partly inrolled into the buccal cavity in the state of contraction. For further demonstration of this point the epithelial layer alone, of the first segment, is represented in the extended and the contracted state in Figs. 3 and 4. It is seen to be greatly thickened as well as inrolled when contracted. The effect of this on the light cells is seen by comparison of Figs. 5 and 6. The light cells are on the basement membrane. The thickening



The figures illustrate certain features of the worm in the extended and in the contracted state. The states of extension and contraction represented are not the most complete possible.

FIGS. 1 and 2 are sagittal sections of the first five segments of an extended and a contracted worm respectively. (*a*) body wall, (*b*) everted buccal cavity slightly protruding, which is used as a proboscis. It is to be noted that the first segment, which is the most sensitive to light, is partly inrolled in Fig. 2

FIGS. 3 and 4 are sections of the dorsal epithelium of the first segment of an extended and contracted worm respectively in the same plane as the last.

FIGS. 5 and 6 give sections of epithelium in the extended and contracted condition. (*l. c.*) light cell.

of the epithelial layer must of course tend to cut off light from these cells. The inrolling of the most sensitive region is another important factor.

The Bearing of Experimental Results upon the Habits of the Earthworm.

It is a truism that in all experiments upon animals the relation of the experimental results to the normal life of the animal should be kept in mind. The behavior of the earthworm has not been systematically studied as a whole except by Darwin. It is obvious that all the experimenters mentioned have studied the reactions of the earthworm in only one phase of its activity, and that phase is not what we should call the normal life of the worm. It is as if the experimenters had chosen the situation of the earthworm as we find it crawling on the sidewalks after a heavy rain as being its typical mode of life. None would probably admit this sooner than themselves, and doubtless they have regarded certain facts as too obvious to require mention. Does the fact that the normal life of the earthworm is carried on in a burrow affect our view of the experimental results obtained? Now the earthworm does spend a portion of its life, during the night time, crawling on the surface of the ground in search of leaves, and also during sexual activity it is less mindful of the light, as is stated. The earthworm leaves its burrow rather reluctantly. Darwin describes the earthworm as retaining the posterior end in the burrow while making searching movements in all directions in search of leaves. In drier weather we know that worms burrow deeply and seldom are found near the surface, depositing their castings in old burrows instead of on the surface.

If the worm is at home almost exclusively in the burrow we should expect those responses which are typical of the burrow life to be better organized and more definite than its activities when crawling in the open. The movements which are typical of the life in a burrow are mainly in the line of the axis of its body. Are these movements and the responses which control them of a more definite nature than its lateral movements? We may first consider the typical burrow movements in response to light. These may be imitated easily by using a screen to shade

the worm or portions of it while crawling on a moist surface, preferably covered with a thin layer of dirt.

If a worm which has been kept in the dark is placed on the moist surface, and the screen is suddenly moved so as to expose the anterior end to light, it contracts the anterior segments slightly, sometimes so slightly as to be barely noticeable, and crawls backward into the shadow. If the posterior end be illuminated in the same way the worm crawls forward into the shade, but after a noticeably longer interval. A slight twitching of the posterior end may be noticed at first, if the light is suddenly turned on. The worm always crawls forward when stimulated posteriorly, If a worm is crawling backward it can always be reversed by stimulating the posterior end. Crawling backward is of course the method by which the worm comes to the surface to eject castings. The two sorts of responses described are of the kind called "photopathic" as distinct from phototactic, and they serve of course to inhibit the worm from leaving its burrow in the light. These "photopathic" responses are very definite and the stimulus calling them forth may be quite weak light. Adams has shown that in very weak light *Allolobophora fœtida* is positive and he suggests that the worm leaves its burrow in response to the stimulus of very weak light upon its anterior end. These observations show that the movements of the worm in its burrow are very definitely controlled by the light, so far as they may come in contact with it by their more sensitive anterior and posterior ends. The middle of the worm is less sensitive to light but its sensitiveness may be shown in the following way.

If the worm is placed on the moist surface exposed to full light from overhead (a 32-candle-power incandescent was used, at a distance of 15 inches) and a screen is then brought over the posterior part of the body leaving the anterior end exposed, the worm does not draw back as when the anterior end was suddenly illuminated. Instead it begins to make random movements in various directions. It may crawl farther out into the light, thus bringing the middle portion into stimulation. This movement is however checked before the more sensitive posterior end is exposed. After a noticeable latent period showing the lower sensitiveness of the middle portion, the worm crawls back under the

shade rather quickly, but usually not completely. The commonest way in which the worm gets under the shade is as follows: It makes all sorts of random movements in every direction, and tries to burrow into the thin layer of dirt, until it accidentally gets the tip of the anterior end under the shadow of the screen. It then at once is oriented, so to speak, and crawls completely under the glass. It may crawl under as if circling around a post. The imaginary post may be exposed to the light so that the posterior part has to crawl forward into the light to get around the post. Usually, however, the anterior end travels faster so as to jerk the middle part under the screen at once.

These so-called "photopathic" reactions are consequently very definite and predictable because they are adaptations important in the normal life of the worm. As compared with the random lateral movements we see that they are controlled by weaker stimuli and are more definite. The anterior and posterior ends are more sensitive than the middle for the obvious reason that the ends alone come into contact to any great extent with light stimulation.

The lateral movements, which are typical of life outside the burrow, are as we have seen of a random nature and less definitely controlled. The worm "dashes back like a rabbit into its burrow," to use Darwin's expression, under a weak stimulus. But when crawling on the surface the same strength of stimulus produces only a general irritation and swaying random movements occur which lead to orientation away from the light only after many trials. With a higher intensity of light the worm is oriented more quickly. Thus we see that a very high stimulus is required to produce a direct sidewise movement away from the light while a very weak stimulus will cause it to move back into its burrow away from the light. The random lateral movements are aptly described by Holmes as "inconsequential vermiculations." But this description does not apply to the movements which are typical of its burrow life. The worm is as definitely adapted to the burrow and as little adapted for life in the open as some other burrowing animals of higher rank that could be mentioned. However this statement must be modified when we consider that a worm exposed to the light on the ground does not

trouble to make random movements but begins to burrow into the soil immediately. After heavy rains we see them washed out of their burrows, and crawling in unwonted places when they are unable to burrow.

Reactions to Mechanical Stimuli.

Perichæta goes through its peculiar jumping movements only under mechanical or similar stimulation, never under the influence of light, so far as we have observed. When touched with a needle on the anterior end it contracts the anterior segments slightly and may begin to crawl backward or it may go forward, lifting its head and making various random movements before settling on any direction. With a slightly stronger stimulus the anterior end turns away slightly from the stimulus. Increase the stimulus and the worm may contract the longitudinal muscles of the opposite side so as to jerk the body around 90 or even 180 degrees, and so give it a new direction. Or the worm may go off into a whole series of jerks, so that there is a complete gradation between the extent of the responses, depending upon the stimulus. More important as determining the extent of the reaction is the condition of the worm. Well-fed worms in fresh condition, when just dug out of their burrow, spring around in the liveliest fashion. If handled they give a series of movements which must make it difficult for an enemy, a bird, for instance, to pick them up before they get a chance to crawl under cover. When stimulated they exude an abundant yellowish mucus. Whether this is an offensive secretion to its enemies is not known to the writer. When a point in the middle of the worm is stimulated the body recoils away from the stimulus at that point and there is a slight swelling due to contraction of the longitudinal muscles, like the contraction and shortening of the anterior end under stimulation. Occasionally the worm may move violently toward the stimulus, but this seemed to be due to an overstimulation producing a complex of effects rather than a simple reflex.

The leaping movements of *Perichæta* are certainly the best examples of random movements that are afforded. They are exclusively adapted to those chance circumstances when the worm gets out of its burrow. They lead in no definite direction,

though they may carry the worm to a considerable distance and enable it to distract the enemy. They are a conspicuous example of the character of most movements of the earthworm, which belong to its limited life outside the burrow.

Conclusions.

The method of reaction to light of the earthworm is far removed from the sort of "trial and error method" of the Infusoria, as analyzed by Jennings. Its avoiding reaction in strong light is of the nature of a definite reflex which causes it to turn directly away from the stimulus, if the whole body is in the light, or to retreat into its burrow, if only the anterior end is stimulated, or go forward if the posterior end alone is stimulated. Methods of trial and error in reaction to light and other ordinary stimuli have clearly been supplanted by more definite responses in all but the Protozoa and certain other low types of animal life. The earthworm's reactions to stimuli, mechanical, thermal, chemical, are in general such as its nervous system and musculature would lead us to expect. The occurrence of random movements in response to all but very strong light is the outcome of the undeveloped condition of its organs of light perception, not to the want of a nervous system and musculature adapted for such simple reflexes. Diffuse organs of light perception may not respond definitely to a localized stimulus unless it is a very strong one. The trial and error method of its responses to relatively weak light are exceptional in character in comparison with its reactions to other ordinary stimuli. Its archaic type of end organs for light gives rise to a type of behavior which is to be regarded as primitive. For the trial and error method is clearly supplanted in the ascending scale of animal life, by reactions of a definite nature, in the case of the simple responses to the ordinary stimuli.

Summary of Results.

1. *Perichæta bermudensis* (Beddard) is an exotic earthworm found sometimes in greenhouses. Its active habits are one of its chief characteristics.

2. The body is less sensitive to light when contracted than

when extended, owing to the fact that when extended the sensitive elements are spread out over a greater surface and become more susceptible.

3. In locomotion, as there are alternate extensions and contractions, there is an alternation of the condition of lower and of higher sensibility. This is important particularly in the sensitive anterior end.

4. As the worm begins each extension in a condition of lower sensibility, it may project its anterior end toward the source of light. This movement is checked as soon as the increased sensibility of the extended anterior end appreciates the stimulus. Movements away from the light do not meet such a check and so are prolonged farther. Orientation is the result of a trial and error method.

5. In strong enough light, random movements toward the light are suppressed altogether, and the worm appears to move directly away from the light without noticeable trial movements. This applies to worms which have been kept in the dark and are in a perfectly fresh condition, as after a time they lose their discrimination and begin to make random movements.

6. Movements in the longitudinal direction are typical of the normal burrow life of the animal, and the axial movements initiated by the anterior and posterior ends are more definitely controlled by the stimulation of light and by a weaker stimulus than are the lateral movements. Lateral movements tend more to be random and are directed only by stronger stimuli because the organization of the worm is chiefly in adaptation to a burrowing life and not to an open air life.

7. The characteristic leaping motion of *Perichæta* is a conspicuous example of random lateral movements, adapted to life outside of the burrow. All gradations may be observed between the ordinary reaction to a slight local stimulus by jerking back, and also bending the body away, if the stimulus be stronger, up to a complete series of leaping movements.

8. Reactions to mechanical stimuli, as well as to other stimuli, chemical, thermal and electric, show that the worm is like other animals as highly organized as itself in responding to a local stimulus of an injurious nature by contracting and bending away

in a definite "avoiding reaction." In this respect the effect is like the response to very strong light. Consequently we see that the random reactions to weaker light have a special explanation and are only an apparent exception to the general form of negative response.

BIBLIOGRAPHY.

Adams, George P.

'03 On the Negative and Positive Phototropism of the Earthworm Allolobophora fœtida (Sav.) as Determined by Light of Different Intensities. Am. Jour. Physiol., Vol. IX., No 1.

Garman, H.

Bulletin of Illinois State Lab. of Nat. Hist., Vol. III., Art. IV. Note p. 74.

Hesse, R.

'96 Untersuchungen über die Organe der Licht-Empfindung bei niederen Thieren. Zeit. wiss. Zoöl., 61, p. 393.

Holmes, S. J.

'05 The Selection of Random Movements as a Factor in Phototaxis. Journ. Compar. Neurology and Psychology, Vol. XV., No. 2, pp. 98–112.

Jennings, Herbert S.

'04 Contributions to the Study of the Behavior of Lower Organisms. Published by the Carnegie Institution of Washington.

Parker, G. H. and Arkin, L.

'01 The Directive Influence of Light on the Earthworm Allolobophora fœtida (Sav.). Amer. Journ. Physiol., IV., pp. 151–157.

Smith, Amelia C.

'02. The Influence of Temperature, Odors, Light, and Contact on the Movements of the Earthworm. Amer. Journ. Physiol., VI., pp. 459–486.

Zoölogical Laboratory,
Northwestern University,
Evanston, Illinois, August 14, 1905.